# Computed Tomography Image Processing with CERA

Technology Excellence in Imaging Solutions

SIEMENS Healthineers

# How to use this PDF

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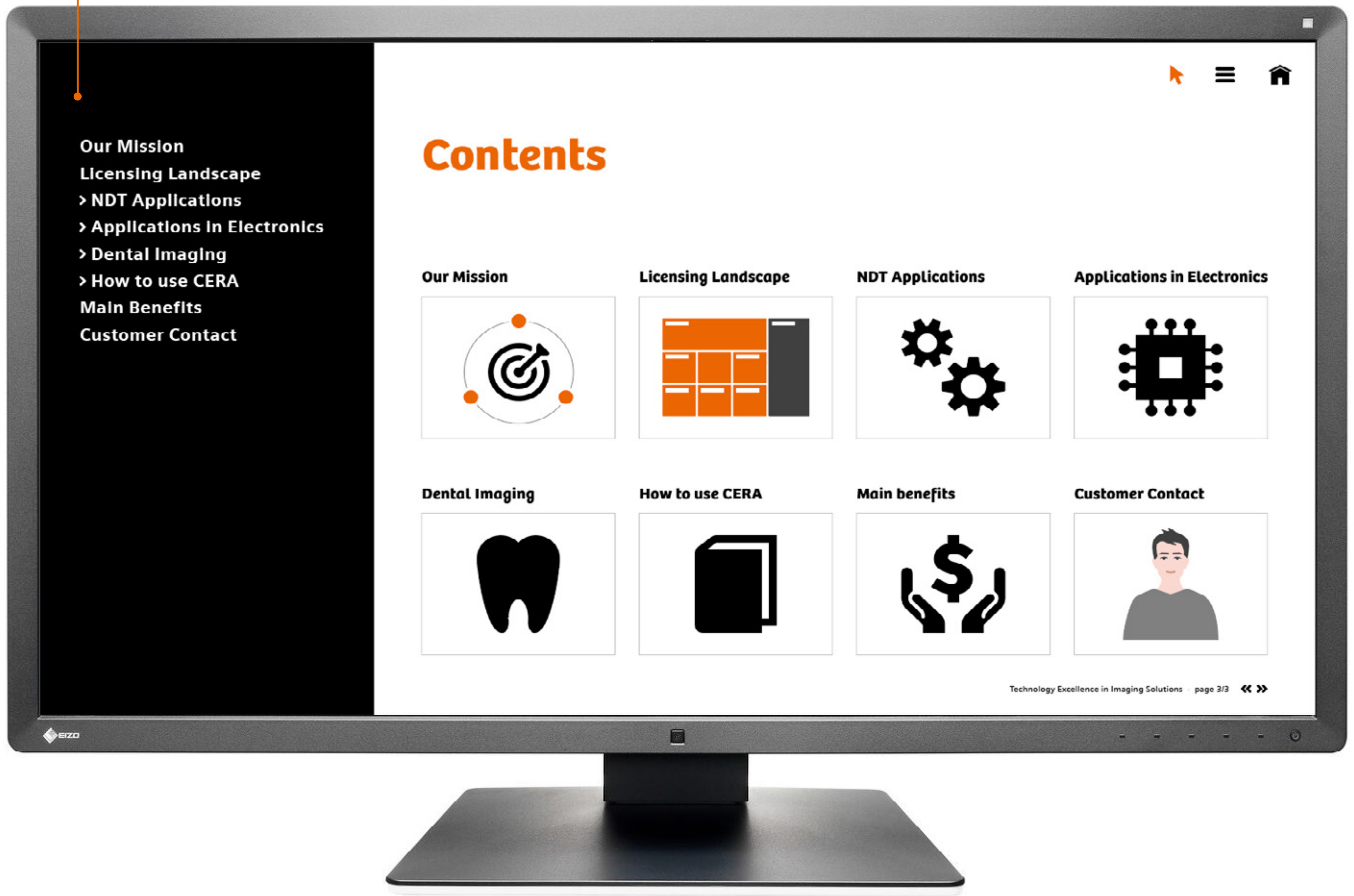


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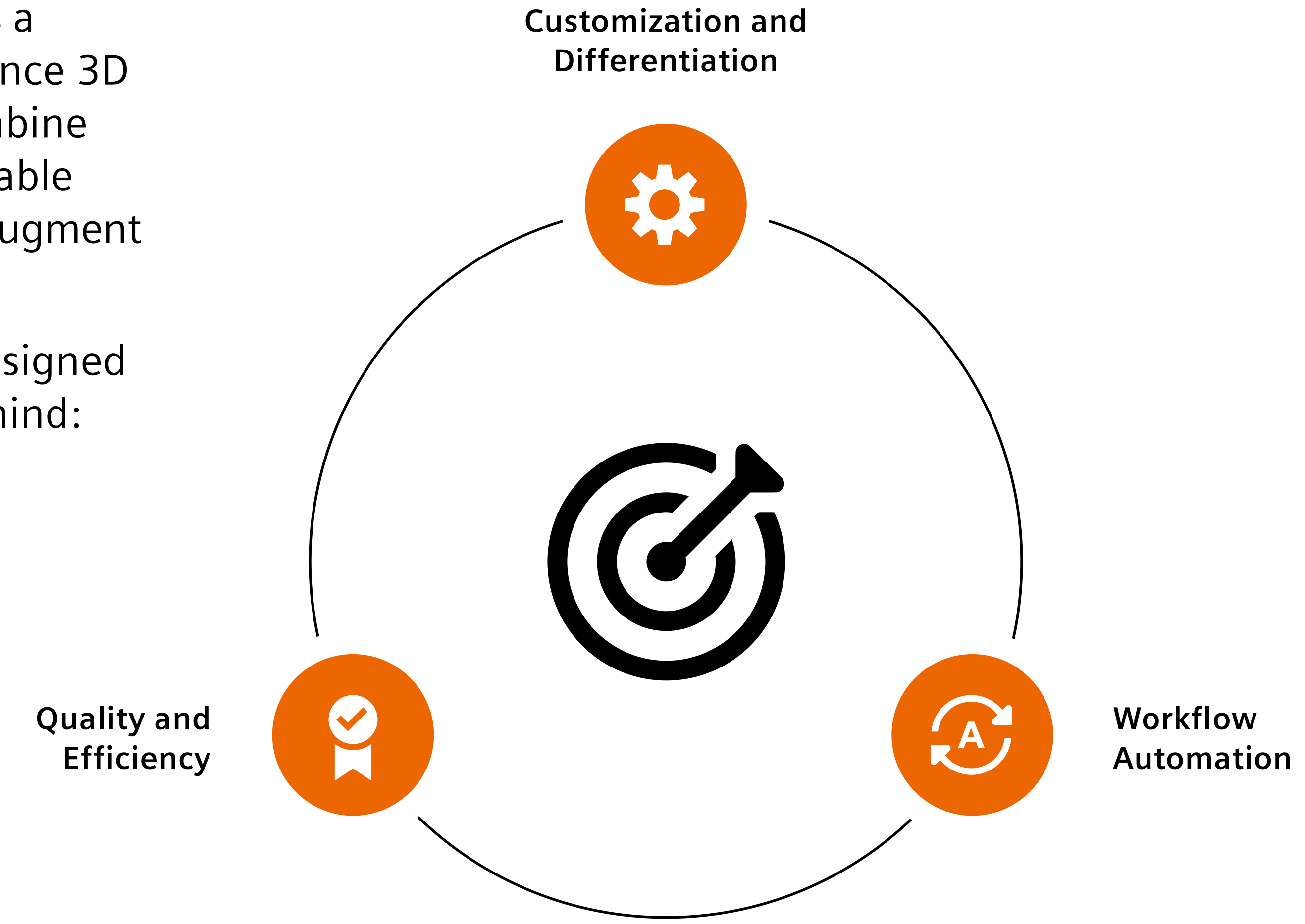
# Our Mission

## To offer distinct Siemens Healthineers know-how for your imaging applications

Over the last decade, Siemens Healthineers has developed CERA as a powerful toolbox consisting of building blocks for high-performance 3D X-ray imaging across various imaging markets. The ability to combine knowledge from diverse application fields places us in a comfortable position to generate and implement innovations that help you to augment your specific solutions.

Regular upgrades add exciting new features to CERA, which is designed to support your imaging needs with the following strategies in mind:



# Our Mission

## CERA functional scope

While 3D X-ray imaging applications are very specialized for their use case, they can be based on a set of common underlying technologies.

The functionality of CERA targets these common technologies by delivering algorithms and functions to be used in a variety of imaging markets. CERA thus offers the opportunity to leverage synergies between otherwise separated communities, applications, and markets.

- Geometry Alignment
- 3D Image Reconstruction
- Image Quality Improvement
- 3D Volume Visualization

# Licensing Landscape

Configurable to specific needs

## CERA BASIC

(Reconstruction package)

### CMP

CT geometry misalignment compensation

### TXR

Exact CT reconstruction

### OMC

Object motion compensation

### SRM

Special CT reconstruction

### RED

CT artifact and noise reduction

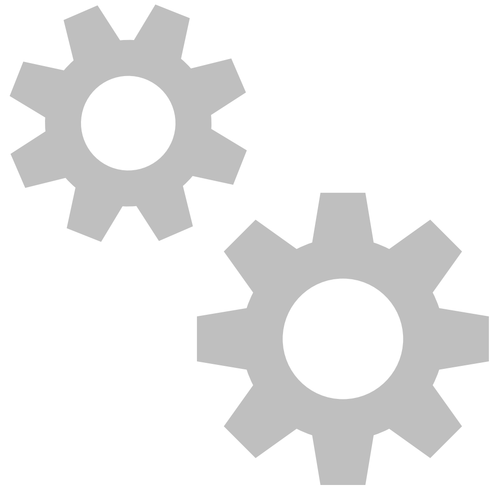
## CERA VRT

(Volume visualization package)

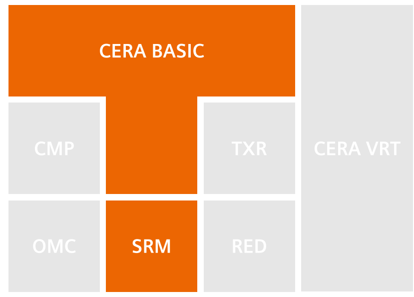
# NDT Applications

Typical applications in NDT comprise dimensional measurement or material testing during the manufacturing cycle of various products.

3D NDT X-ray imaging often has high demands on resolution and geometric precision and often involves very large amounts of data. CERA supports these requirements well.



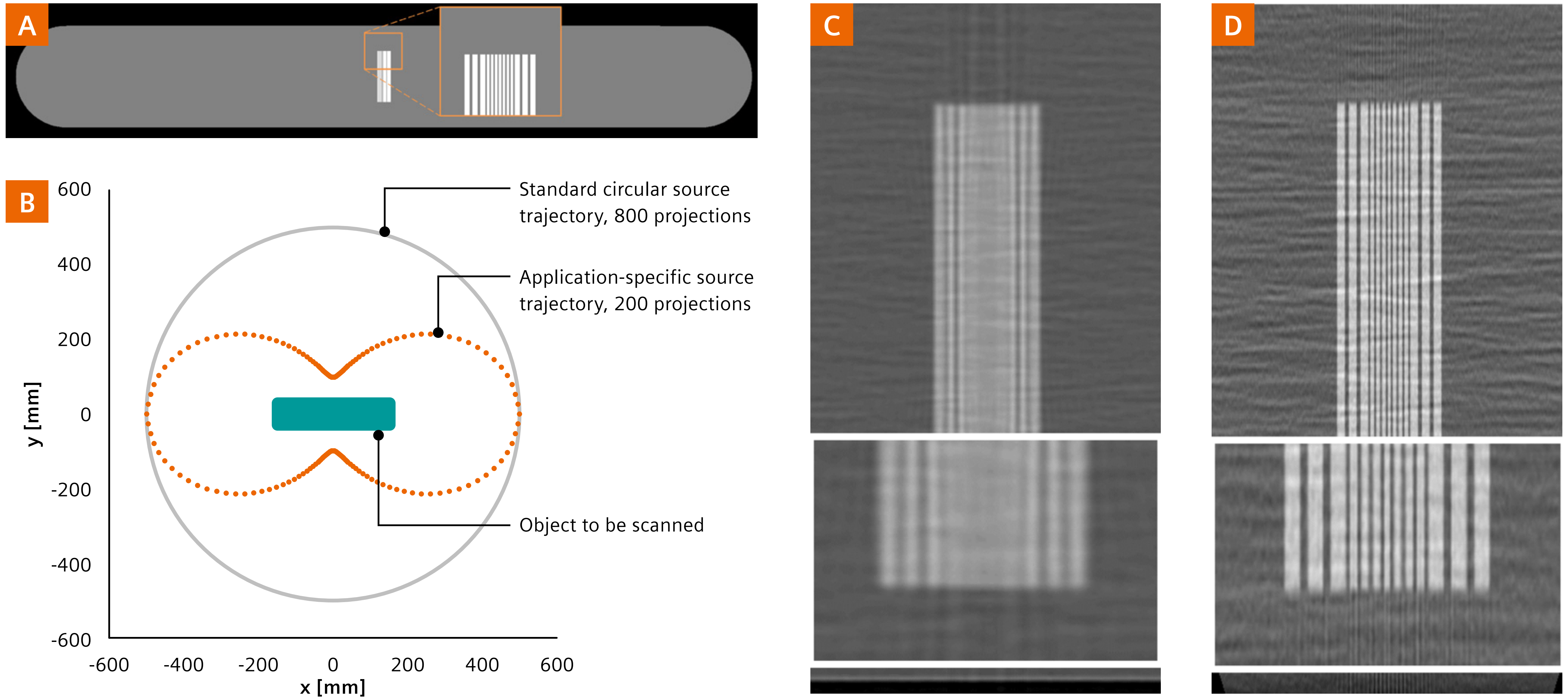
# Application-specific Trajectories




## Improved image quality over Feldkamp with fewer projections

CERA's SRM pipeline offers a modern, more flexible alternative to the standard Feldkamp pipeline. Not being restricted to circular trajectories, fixed magnifications or fixed angular increments, it allows the scan geometry to be optimized to the 3D imaging task at hand.

Possible use cases include the handling of irregular fields-of-view, the selective increase of spatial resolution or the significant reduction of projection numbers.



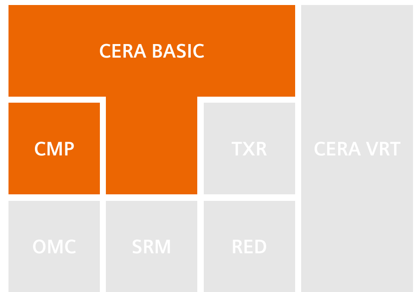

(A) Top view of whole object, highlighting the area of interest.

(B) Top view of scan trajectories.

(C) Standard circular scan, 800 projections, reconstructed with FDK pipeline.

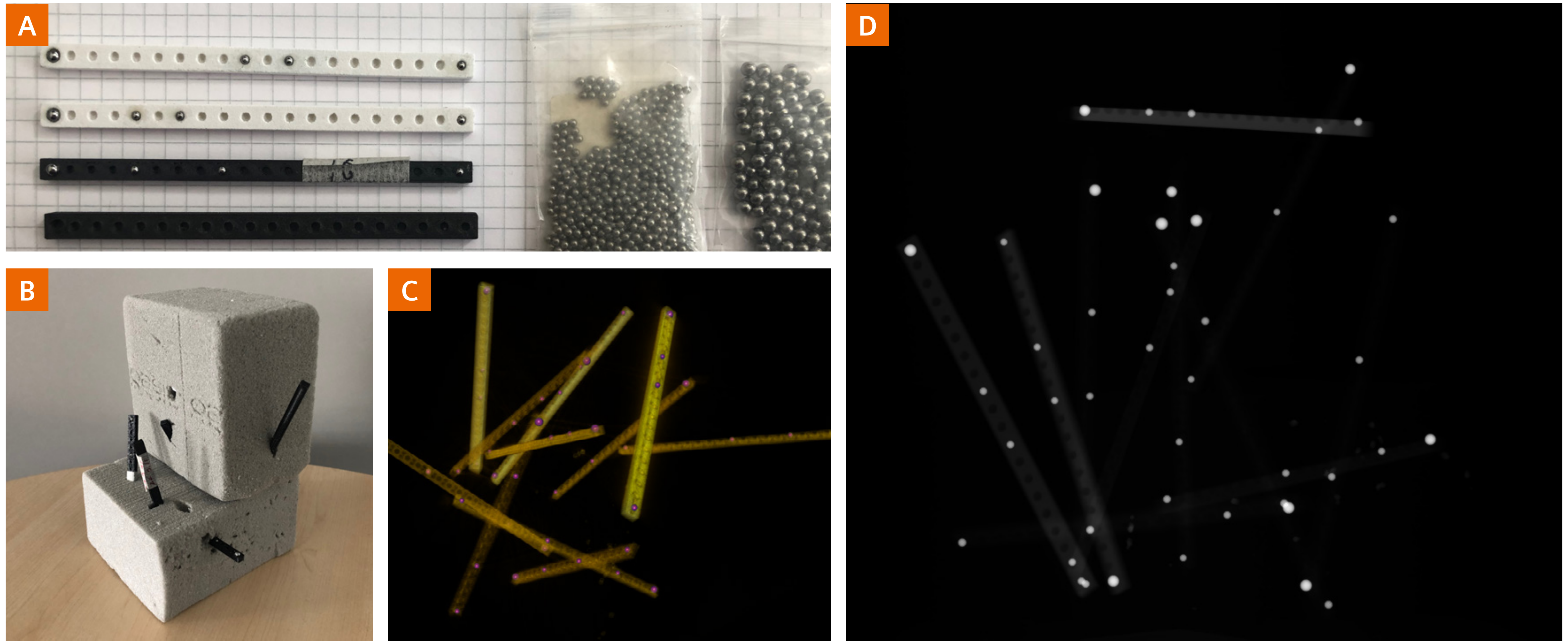
(D) Optimized scan, 200 projections, reconstructed with SRM pipeline.

# Phantom-based Alignment




## Computing one projection matrix for each freely positioned view

CERA contains a method to determine the scan geometry, based on a physical phantom. A suitable phantom can be easily built and adapted to specific application requirements: it is based on a set of linear segments, each composed of four spherical markers arranged in a unique manner along a straight line. Our method does not require an accurate – and expensive – phantom to be built, but instead requires one initial 3D CT scan of the alignment phantom that can be manufactured at low cost. After learning the actual phantom, it computes and outputs one projection matrix for each X-ray image of this phantom.



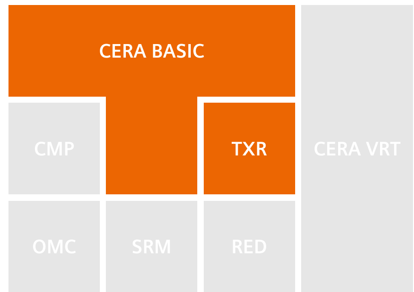

(A) Material to build PBA phantom.

(B) PBA phantom.

(C) 3D PBA phantom model due to reference scan.

(D) PBA phantom projections.

# Cone-beam Artifact Free Reconstruction

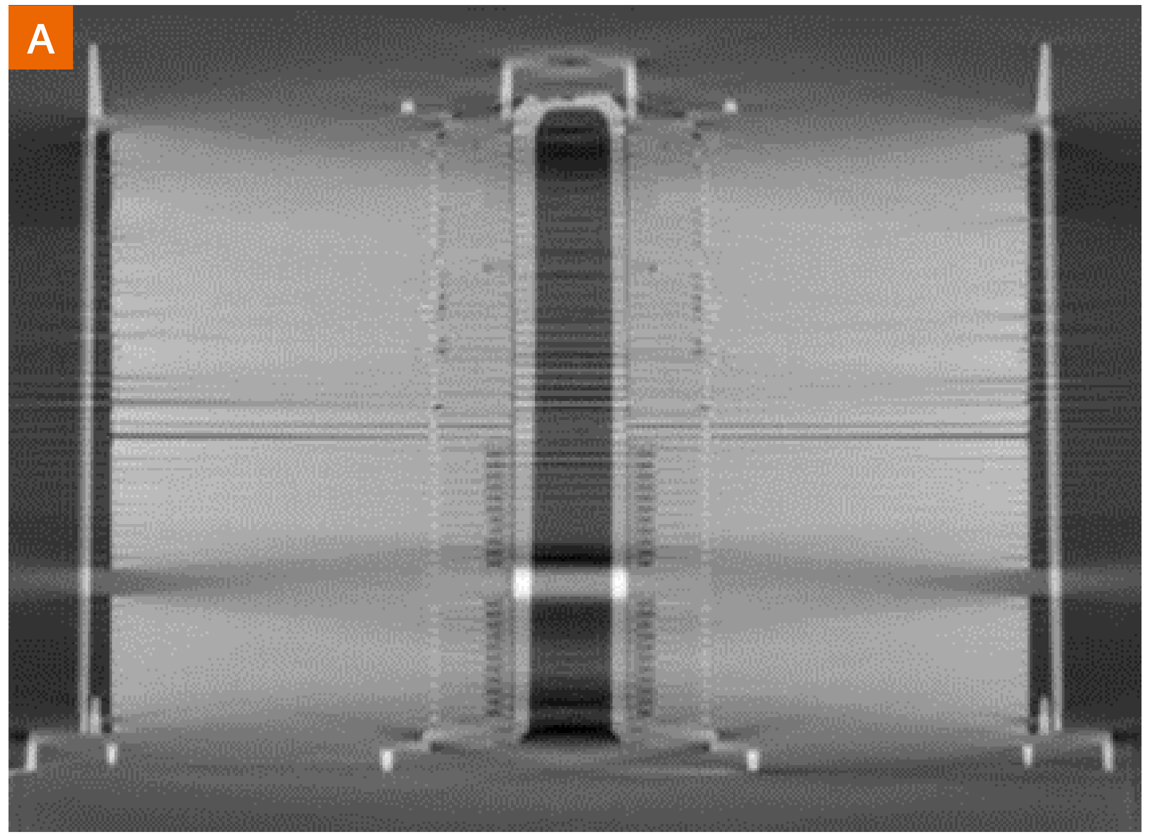


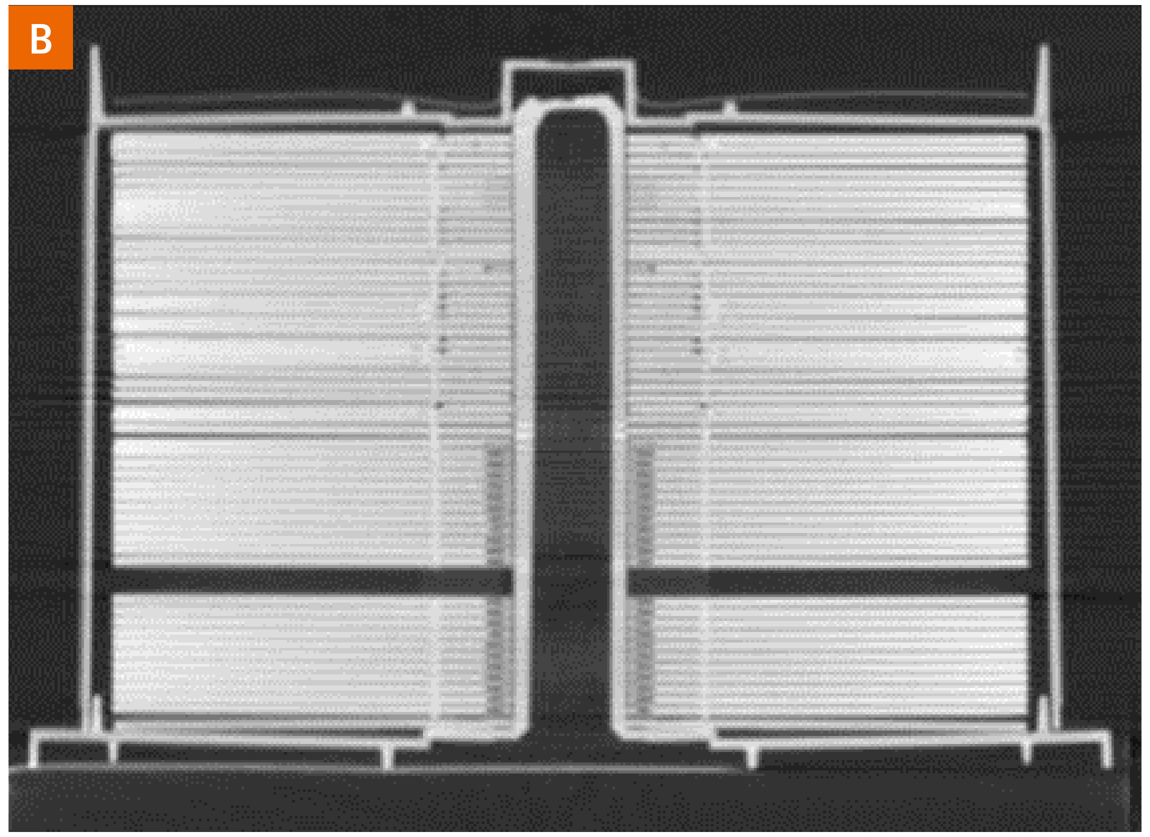

## Full utilization of helix or circle-plus-line scans

CERA provides theoretically exact reconstruction algorithms which completely resolve the cone-beam artifacts problem for helix, circle-plus-line, and circle-plus-arc trajectories.

This results in sharper object edges than in a typical Feldkamp-like imaging workflow.

Reconstruction is performed in a filtered back projection manner, and thus significantly faster than iterative approaches for those trajectories.

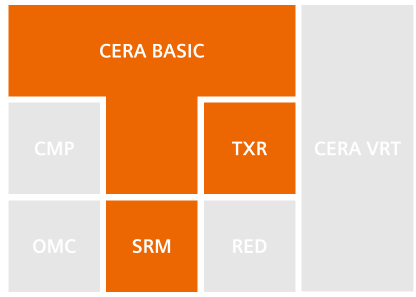



(A) Vertical reconstructed slice of a scanned stack of DVDs using full-scan FDK.

(B) Result of a circle-plus-line reconstruction of the same object, showing no cone-beam artifacts.

# Field-of-view Enlargements




## Maxing out existing scanner hardware

CERA supports various methods to extend the field of view.

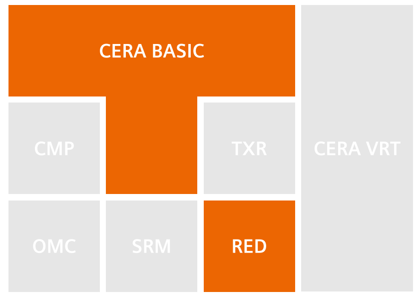
**Half-beam:** The radius of the field of view can almost be doubled by a single 360 degrees scan where the rotation axis is projected closely to a detector edge.

**Extended field of view:** The size of the field of view can be multiplied using multiple circular scans with a shifted detector or a shifted turntable.

**Dual helix:** The extended field of view mechanism can be used with two helical scans to increase both, height and radius of the field of view.

For improved image quality, all features utilize scan data in its native geometry without any projection stitching.

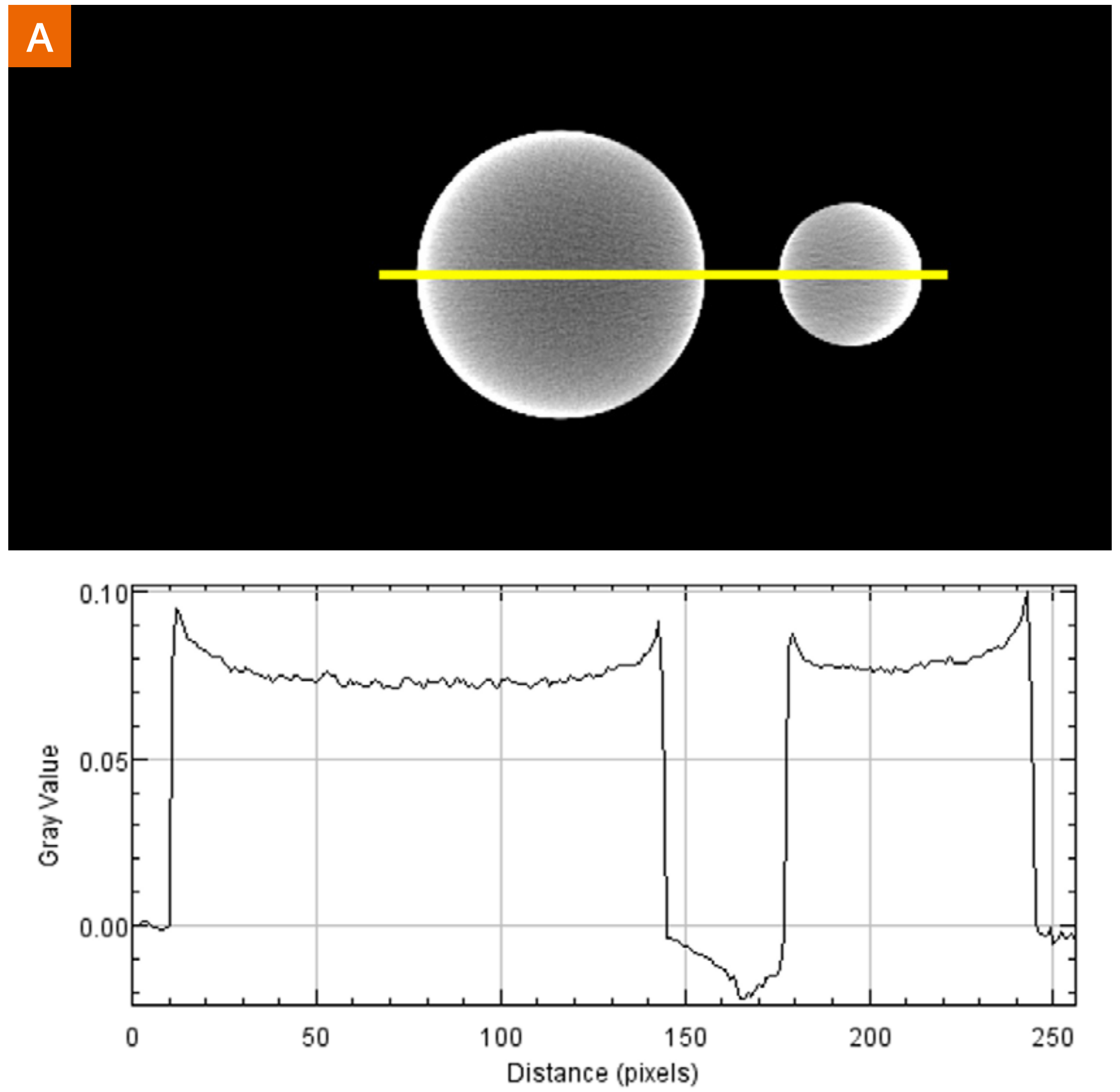
# Beam Hardening Reduction

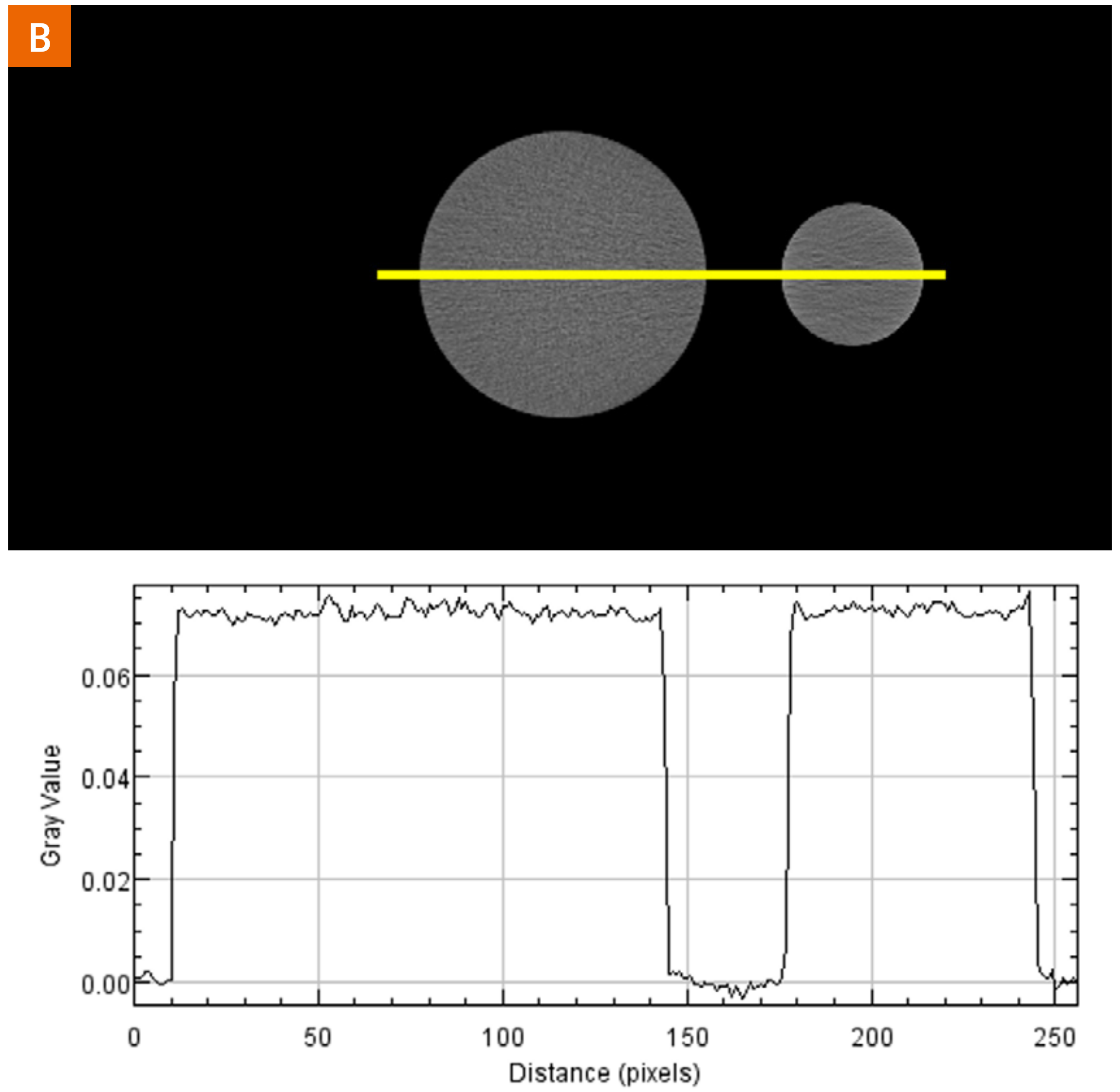



## Various methods, from automatic to fully configurable

CERA involves beam-hardening reduction methods that preprocess 2D projection images according to a predefined model which can be obtained by various sources. For example, it can be automatically derived from the content of the acquired projections.

Alternatively, the model can also be specified by the user applying knowledge about object materials and X-ray spectrum.

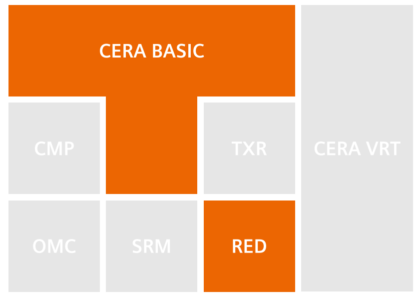



(A) Two-spheres object, reconstructed w/o beam hardening reduction.

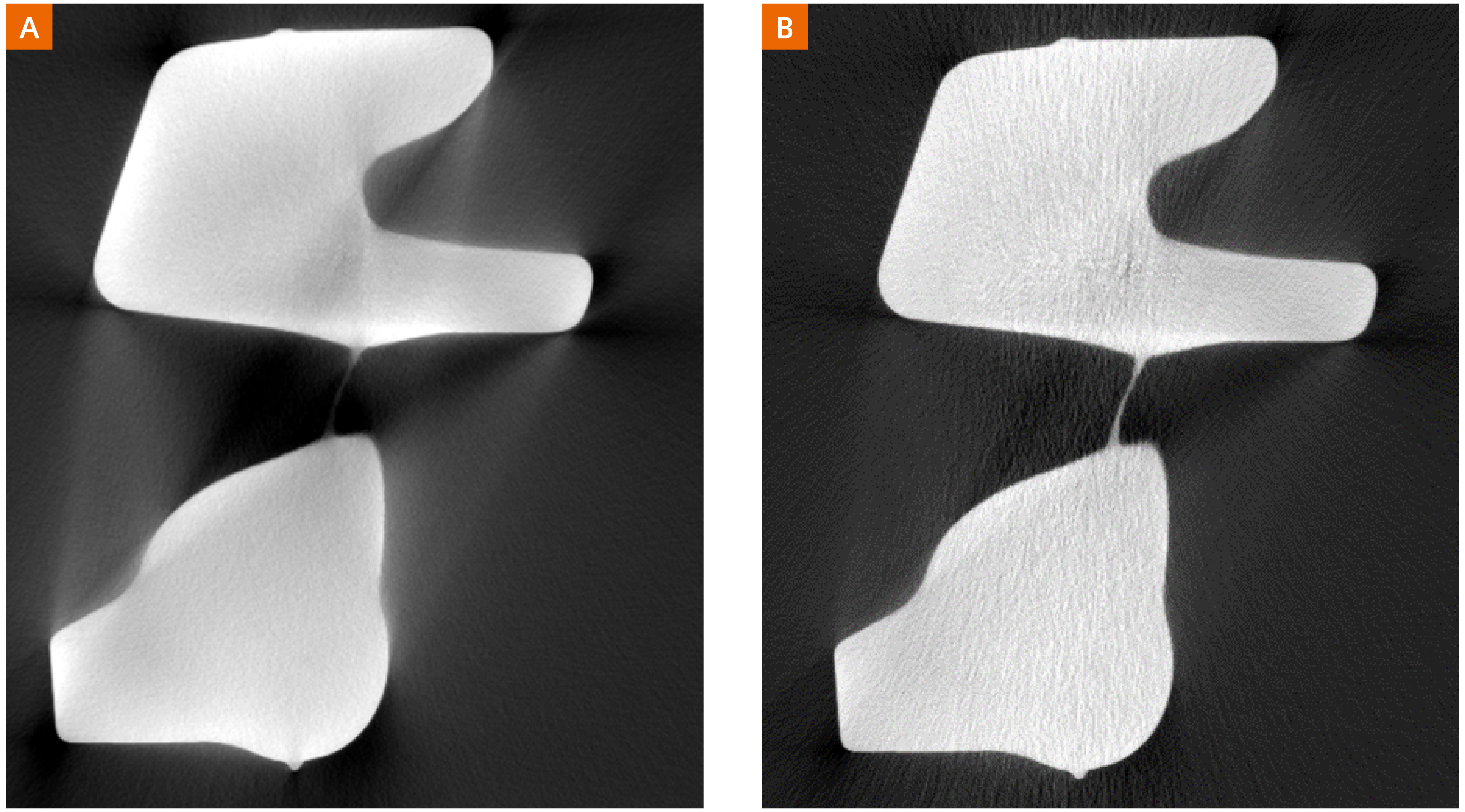
(B) Reconstruction with beam hardening reduction enabled.

# Scatter Reduction




## Training a transferable, use case adaptive software model

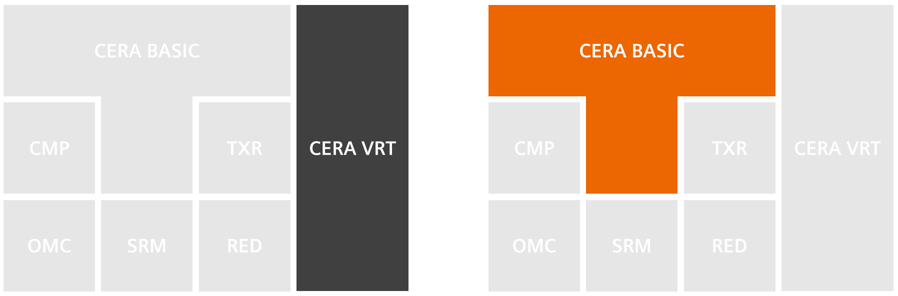
CERA's model-based software scatter reduction method involves a pre-scan to calibrate the characteristic scatter model of a scanning configuration. The pre-scan calibration supports measurements with a beam-stop array (BSA), a beam-hole array (BHA) or a slit-collimation, providing a flexible solution for a specific X-ray system. The number of pre-scan projections required to gather proper statistics can be relatively small (typically 10-50). A scatter characteristic determined once can then be transferred to similar CT scans with similar objects for efficient re-use.




(A) Scatter reduction disabled.

(B) Scatter reduction enabled.

# Tera Voxel Renderer




## Visualization of almost arbitrarily large volumes in real time

In contrast to standard volume rendering techniques, CERA's teravoxel renderer allows the fluent visualization of 3D volumes that are only limited by available mass storage capacity.

Iterative refinement of Tera Voxel Rendering (2048^3 volume using only 512 MB GPU memory)

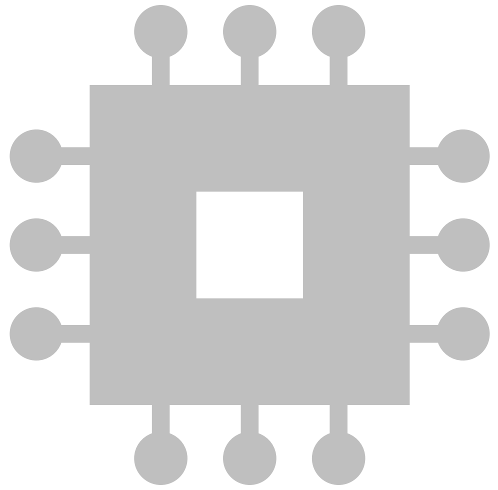
# Benchmarks

| | | FDK | SRM |
|---|---|---|---|
| RTX 2080Ti | Peak GUPS | 270 | 235 |
| | Typical GUPS | 233 | 192 |
| | Example: 1500 x $1500^3$ | 22 s | 26 s |
| RTX6000 | Peak GUPS | 306 | 274 |
| | Typical GUPS | 270 | 237 |
| | Example: 2000 x $2000^3$ | 59 s | 67 s |
| RTX8000 | Peak GUPS | 328 | 297 |
| | Typical GUPS | 298 | 263 |
| | Example: 2500 x $2500^3$ | 131 s | 148 s |

**GUPS:** Giga-Updates Per Second
**GU:** Giga-Updates (one image projected on 1 billion voxels, 100 images projected on 10 million voxels, ...)
**Typical values are:** Volume dimension skew in [0.9, 1.1], number of GU (Giga Updates) larger than 80% of example values
**Volume dimension skew:** sqrt(#voxels per slice) / #voxels in z-dim

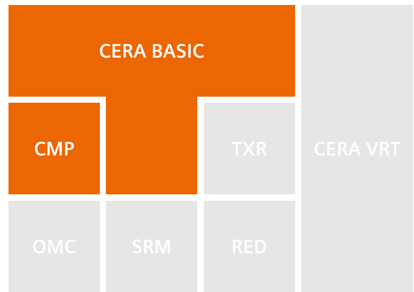
# Applications in Electronics

Electronic testing typically deals with objects of anisotropic form factors, such as printed circuit boards, oftentimes with a specific interest in only certain regions distributed over that object. The small structures of interest demand high geometric magnifications during the scan. In addition, fast workflows are required in in-line applications.



These requirements are often addressed with linear or circular tomosynthesis scans with a reduced number of projections. CERA's dedicated analytic and iterative algorithms provide high image quality in these scenarios. Geometric jitter caused by fast movement of manipulators and amplified by high geometric magnification is reduced by CERA's automatic jitter compensation. Visual assessment is enhanced with cutting-edge visualization techniques.

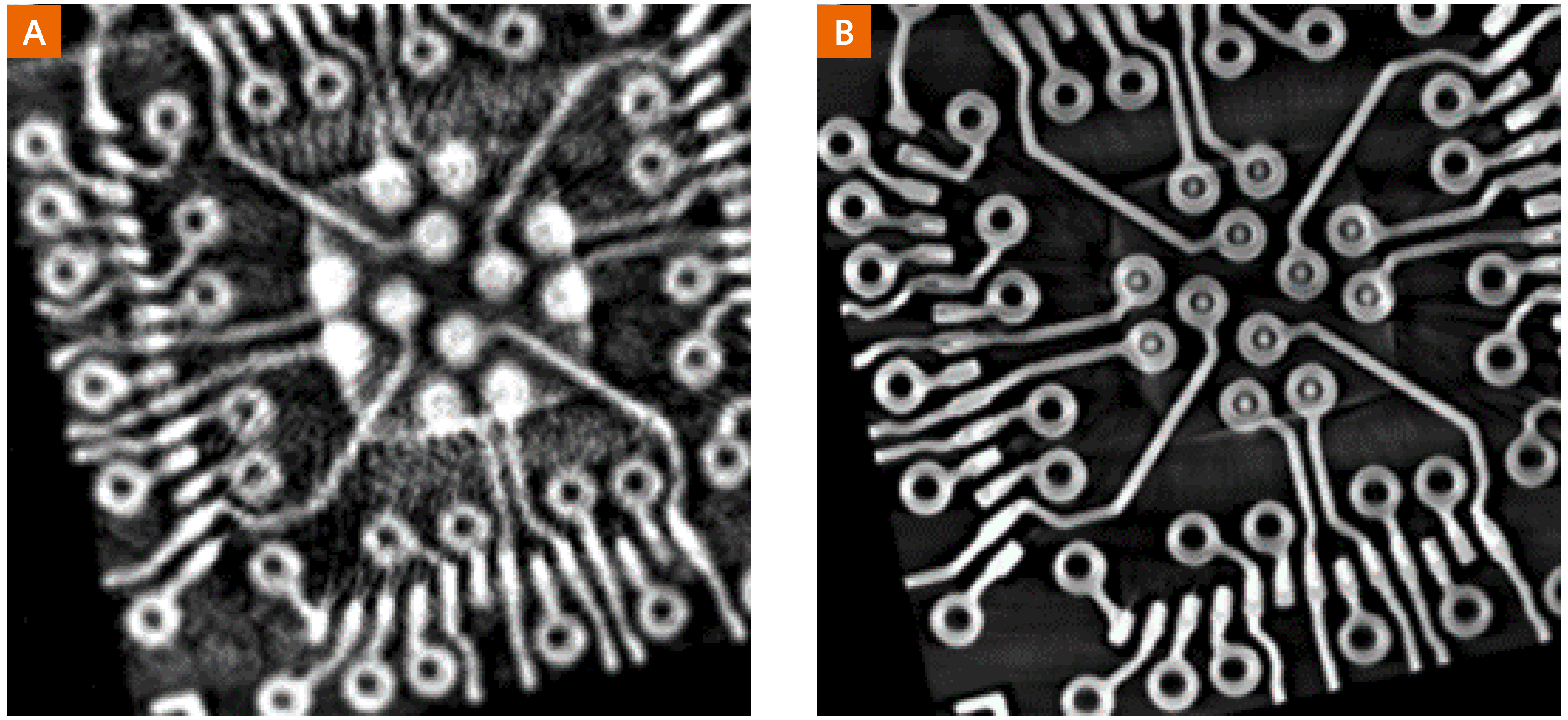
# Jitter Compensation




## Auto-focus for 3D X-ray imaging

In industrial CT systems the acquisition geometry usually deviates slightly from the ideal geometry due to (systematic or stochastic) mechanical deviations. Such deviations comprise inaccurate determination of the rotation axis, tilts, or rotations of the detector and similar effects. Even small variations in the subpixel range will lead to artifacts and distortion in the reconstructed volume.

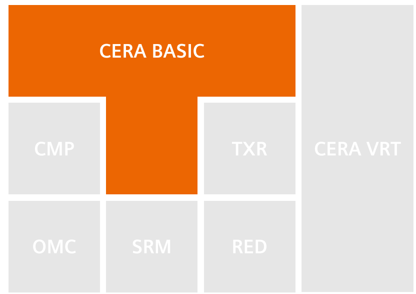
CERA's jitter compensation and auto alignment aim to automatically detect geometric inaccuracies from the acquired projections only and to compensate for those during 3D reconstruction. This often significantly improves image quality without the need for invasive approaches such as the placement of geometric markers on the object.




(A) No jitter compensation.

(B) With jitter compensation.

# Iterative Reconstruction



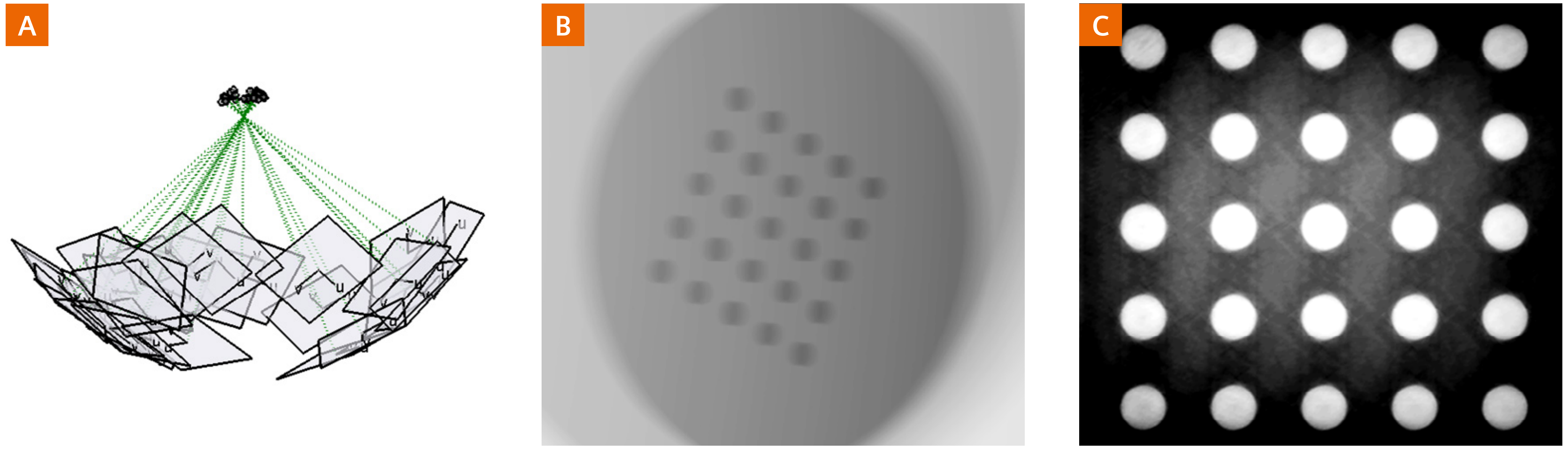

## Reconstructing any set of arbitrary projections

CERA’s modern iterative reconstruction pipeline enables scan modes for which analytic imaging methods do not provide appropriate solutions. Examples are few-view imaging set-ups or robotic scan modes where the source positions do not describe a connected trajectory.

CERA offers advanced iterative algorithms, such as
- a filtered iterative method that introduces advantages of analytic (FBP) CT imaging algorithms to the iterative world,
- Sparse-ART that is specifically designed for imaging sparse objects, and
- methods to utilize prior knowledge for further optimization of image quality.

CERA's high-performance implementation allows for fast product workflows using iterative methods.

**Example of iterative reconstruction of a BGA from 30 projection images with random projection angles**



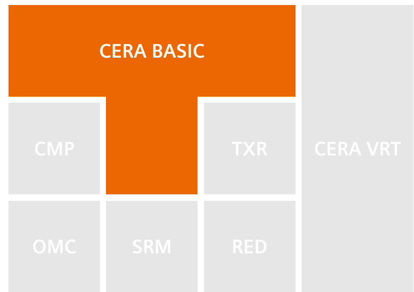

(A) Robotic tomosynthesis scan geometry.

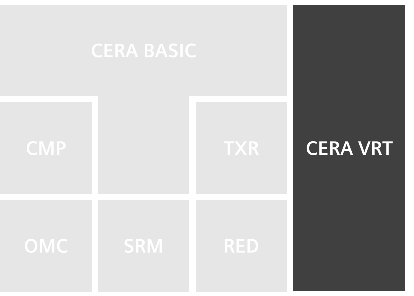
(B) One example projection.

(C) Reconstructed slice.

# Cinematic Rendering

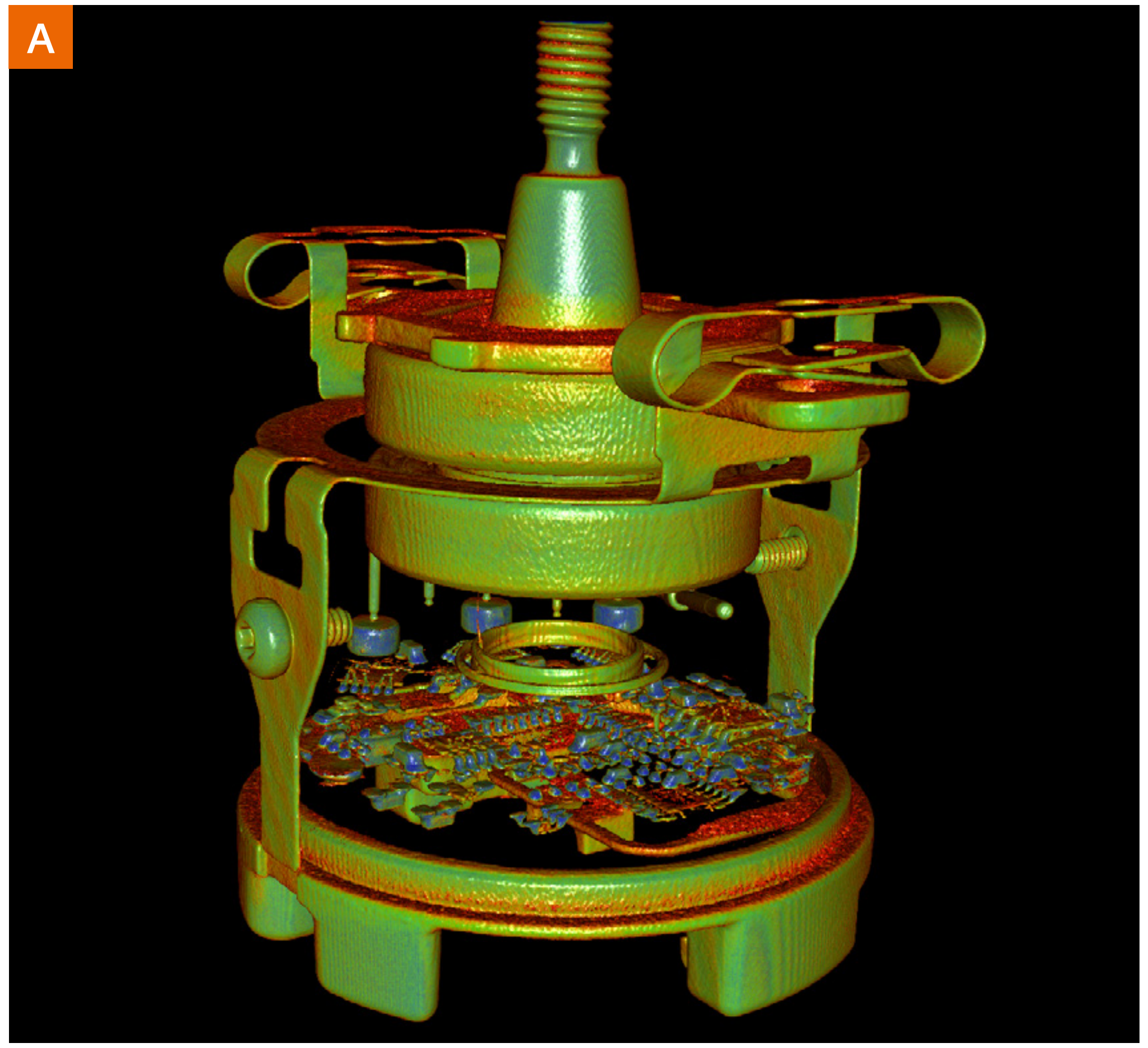
## Transforming volumes into photos




CERA's Cinematic 3D engine renders photorealistic images by stochastically considering relevant optical phenomena of the scene, such as scatter, color and shape of light sources, environmental lighting, and others.

Despite its underlying computational complexity, a responsive user experience is achieved by CERA's highly optimized GPU implementation.

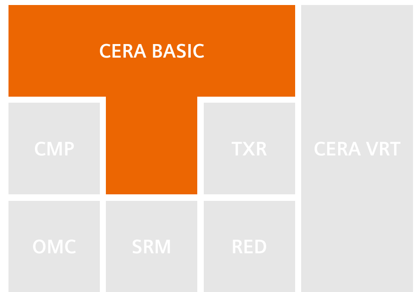




(A) Standard rendering

(B) Cinematic rendering

# Speed-up Methods



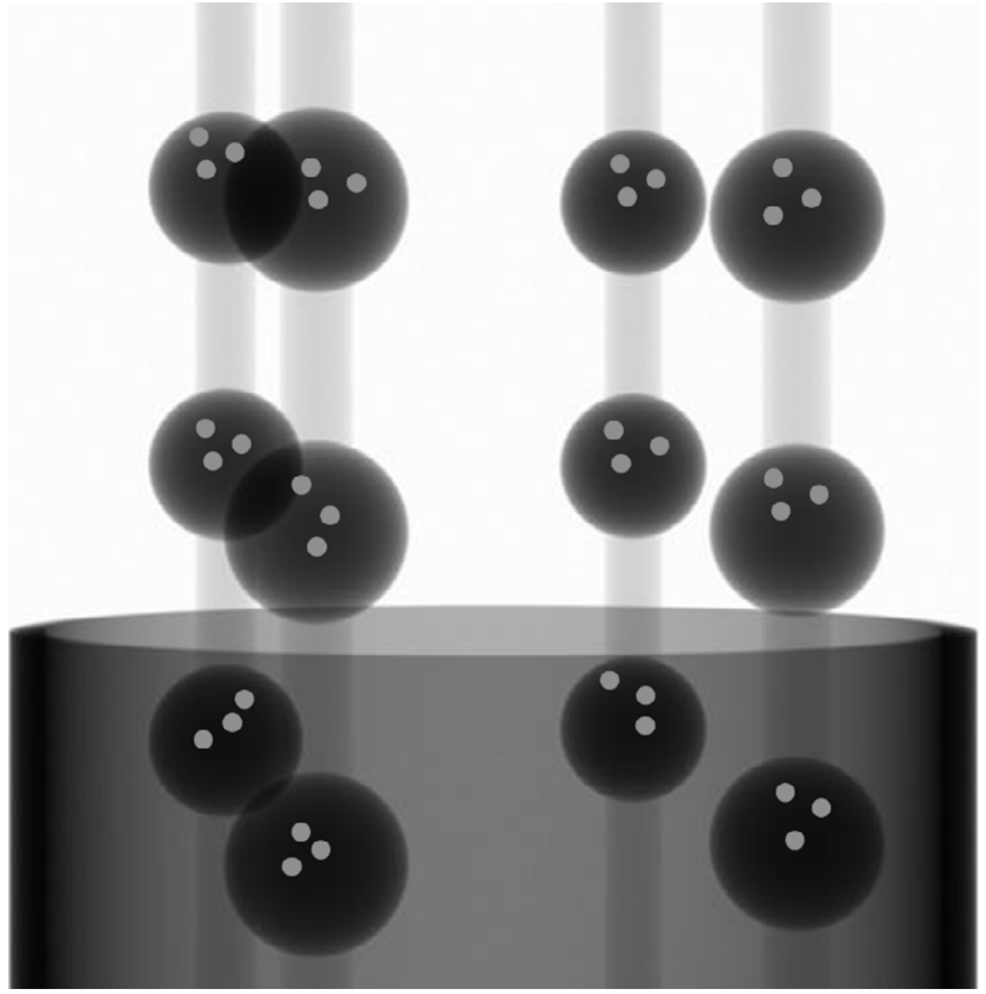

## Even faster reconstructions

CERA algorithms are already designed for high-performance and are heavily tuned to the supported GPU generations. In addition, algorithmic features allow users to easily reduce reconstruction times for given tasks even further.

**Empty Space Skipping**
This feature is designed to avoid computations in regions that are detected or defined as empty. Thus, a noticeable speed-up can be achieved for objects that cover the field of view only partially, such as multiple small production parts mounted on a holding frame or, say, a bicycle rim.

**Dynamic Optimization**
With this feature, CERA automatically adapts its fine-tuning to the specific computer hardware and reconstruction configuration. This learning phase can occur offline, as a pre-step, or online during reconstruction.

**Region-Of-Interest Reconstruction**
CERA supports the efficient reconstruction of individual subvolumes in a single reconstruction workflow. Thereby, projections are preprocessed only once, minimizing data transfer and computational effort. Furthermore, volume memory is only required for the regions of interest.

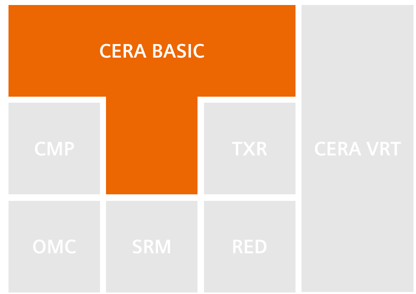


Sample empty-space-skipping use case: several ROIs separated by air gaps.

# Dental Imaging

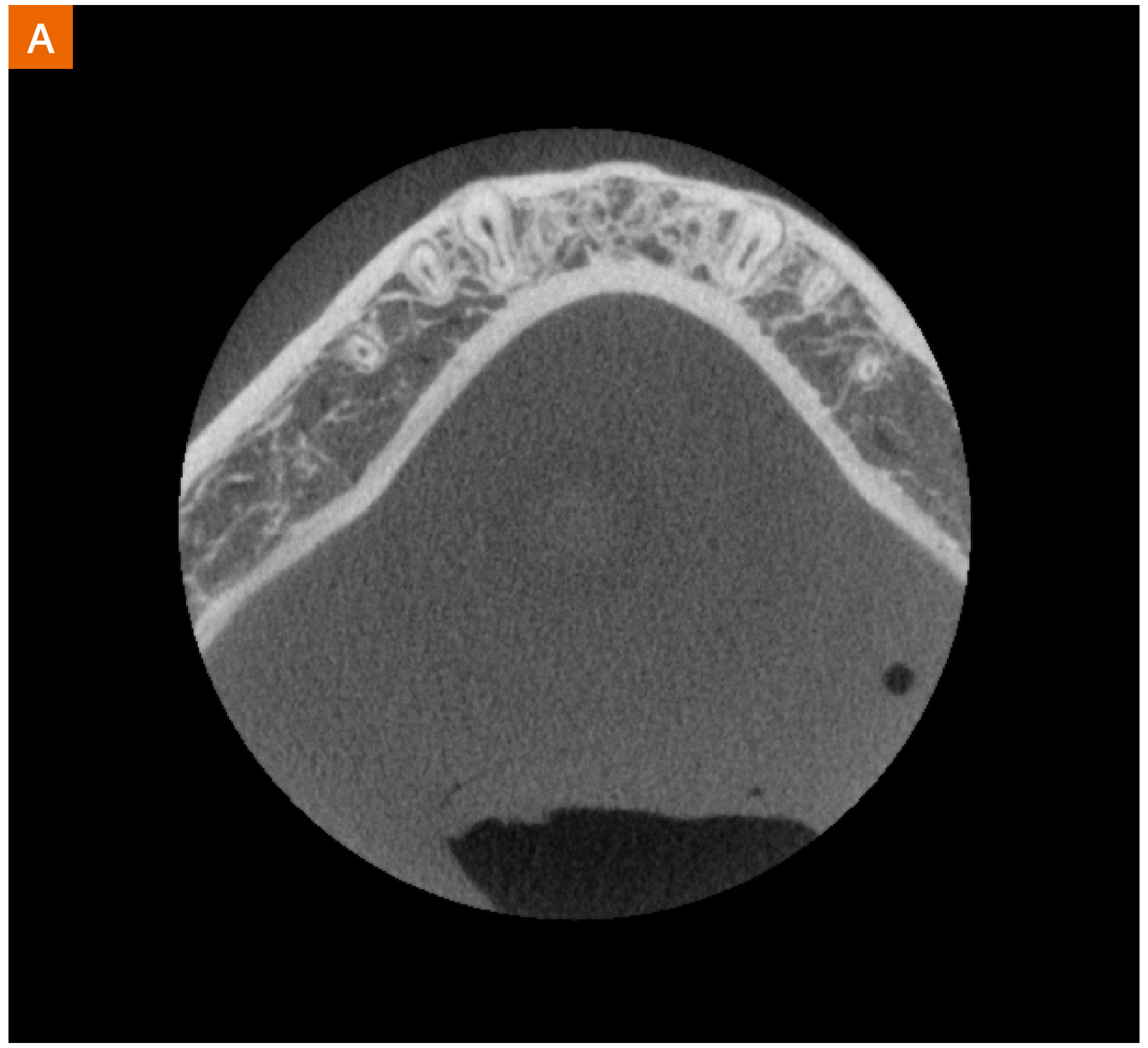
Digital volume tomography has become a standard application in dental imaging. Good algorithmic processing allows very compact and cost-efficient designs to be created for highly specialized devices for imaging the human head. Typical challenges are detectors that do not cover the patient's entire head, limitations in the system mechanics, patient motion, and metallic dental fillings. This chapter presents the solutions CERA delivers for those challenges.

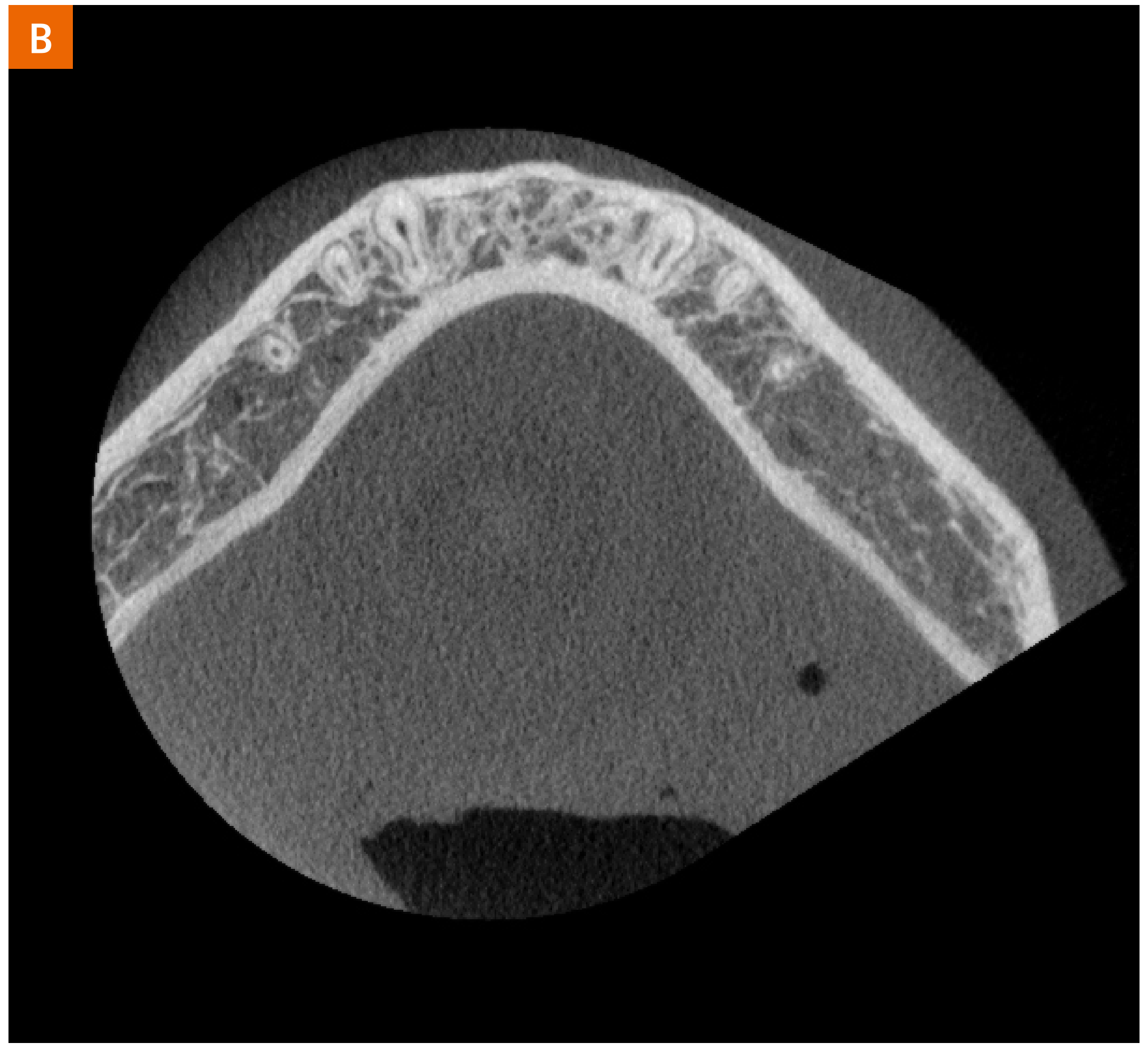
# (Super) Short-scan Reconstruction




## Optimized scan protocols

Acquistion modes with less than a full rotation around the patient are supported through CERA's short-scan and super short-scan algorithms. These allow imaging of an off-center region of interest in high quality from projections collected within a rotation of 180 degrees or even less. Benefits are a reduction in effective patient dose, a shorter acquisition time, and a potentially enlarged scanning volume.



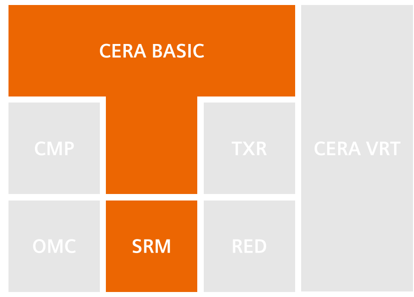




(A) Full-scan reconstruction.

(B) Short-scan reconstruction using only 2/3rds of full-scan projections.

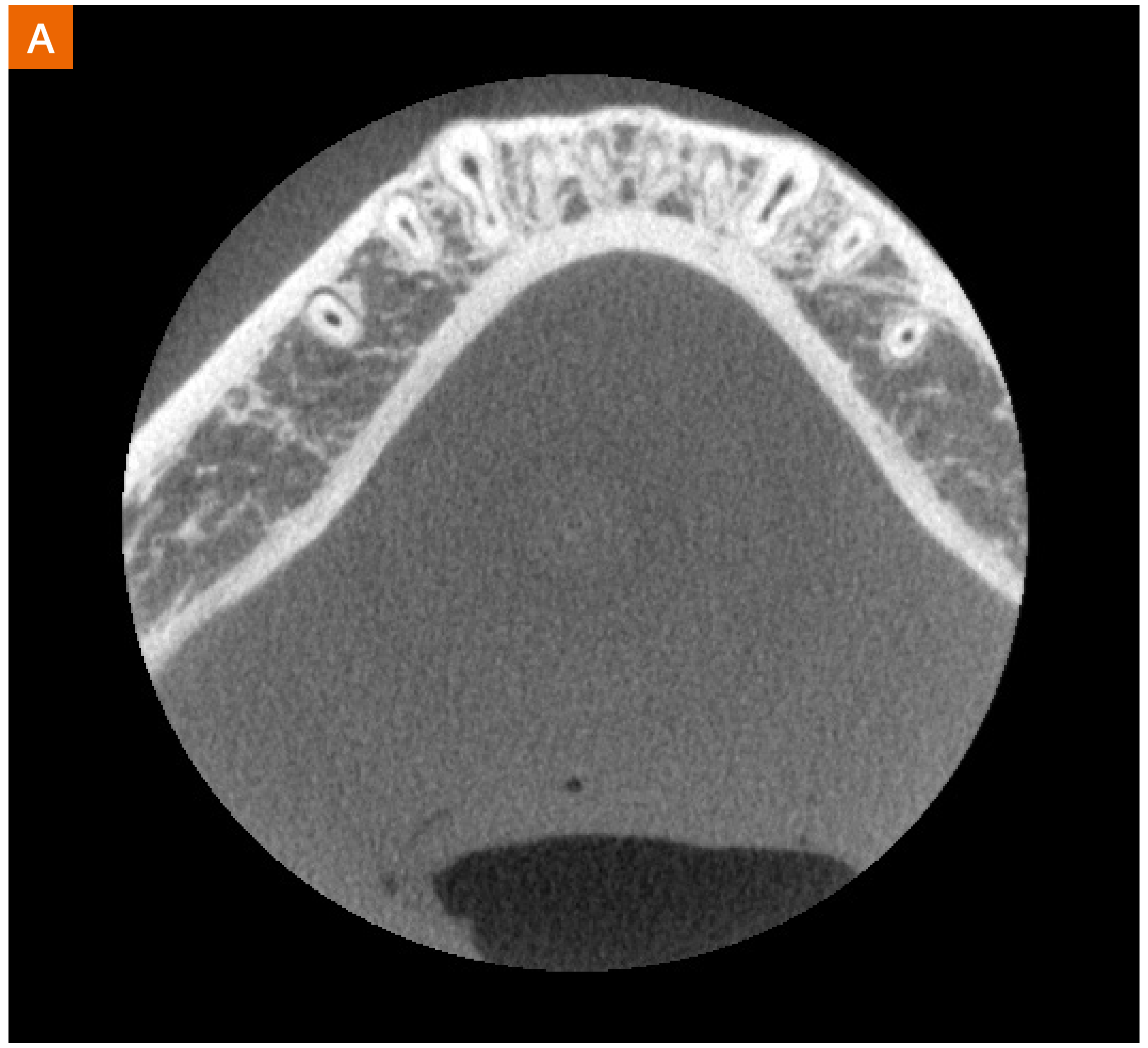
# Half-beam Reconstruction

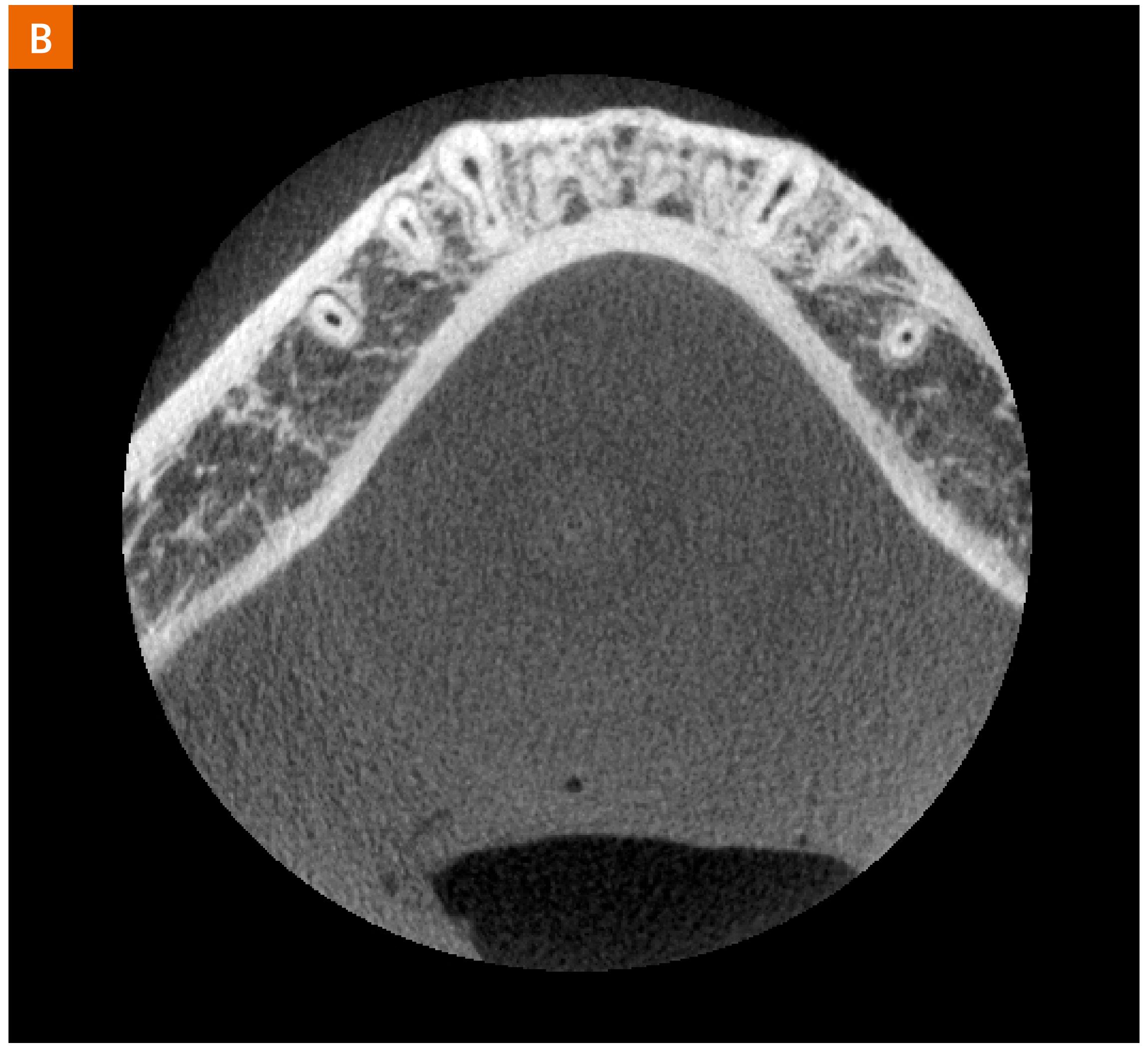
## Allowing larger scan volumes




In a standard 360 degrees scan, the information about the patient is measured twice. This redundancy can be utilized to reduce detector costs. With CERA's half-beam reconstruction method, the full volume can be reconstructed with a detector of significantly reduced width.

This benefit is achieved maintaining both reconstruction speed and image quality. As a side-effect, scattered radiation is reduced as a smaller portion of the head is irradiated.



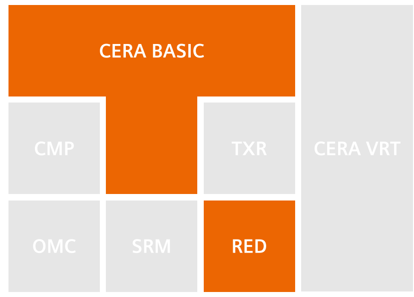




(A) Full-scan reconstruction.

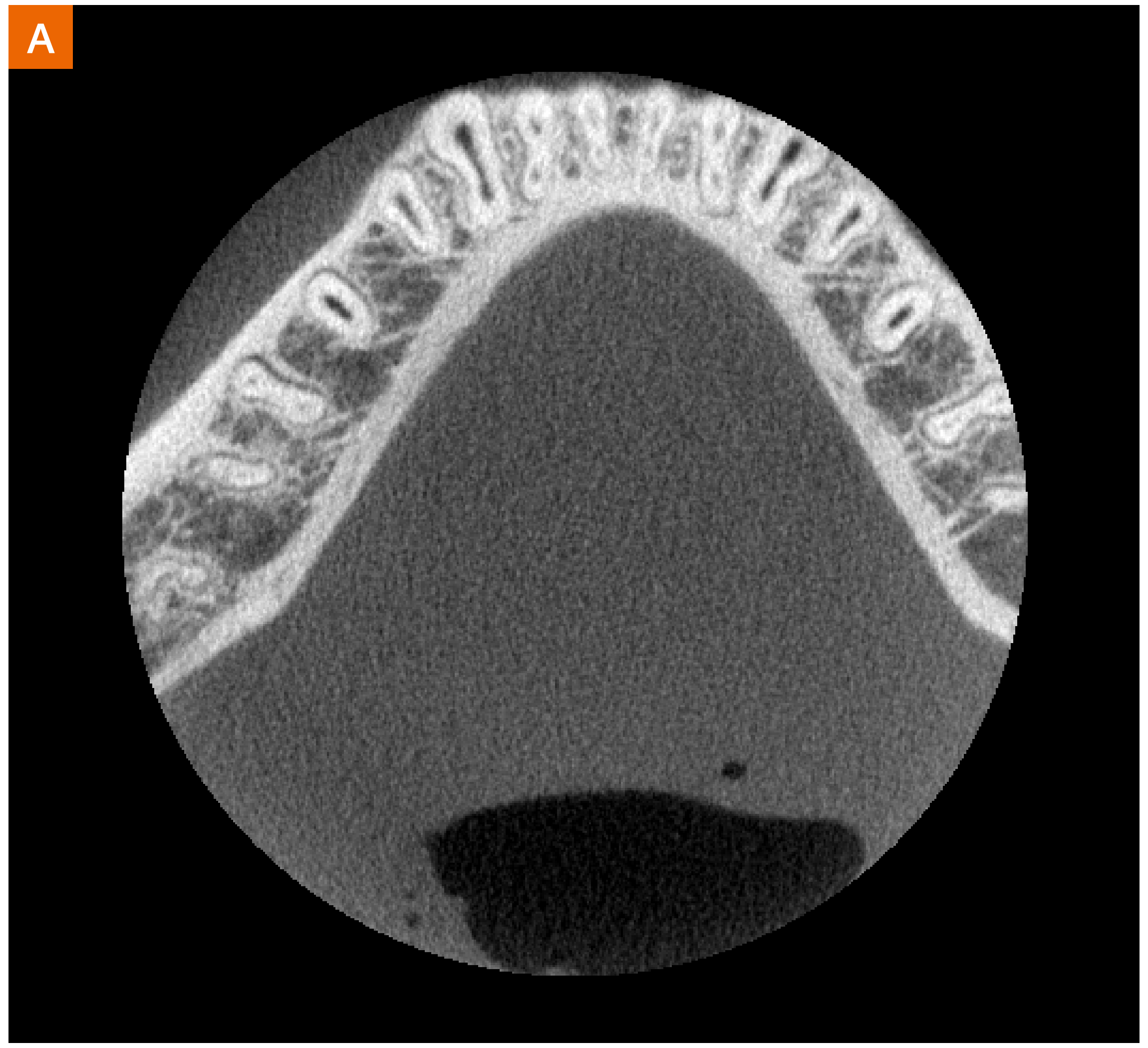
(B) Half-beam reconstruction with half-size detector.

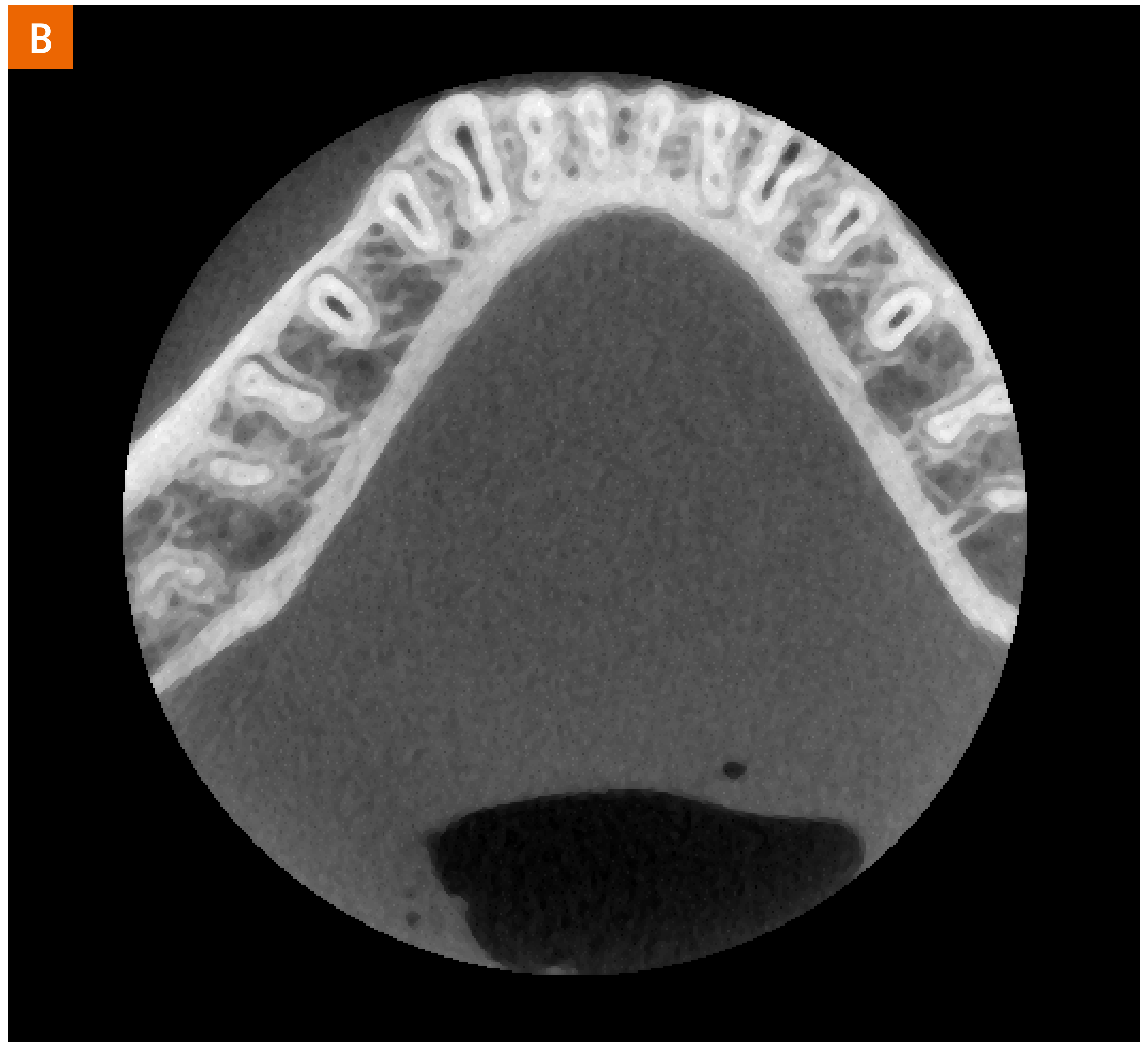
# Noise reduction

## Saving X-ray dose and scan time




Using low power X-ray tubes and faster scan modes results in lower total dose and thus in increased image noise. CERA provides adaptive and structure-preserving noise reduction algorithms that act during different processing stages, simultaneously in the projection domain and in the volume domain. These algorithms allow similar image quality to be achieved with reduced tube current, reduced exposure time and reduced dose.

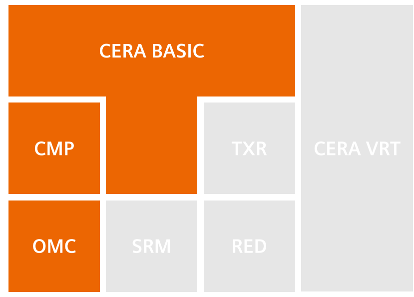



(A) Noise reduction disabled.

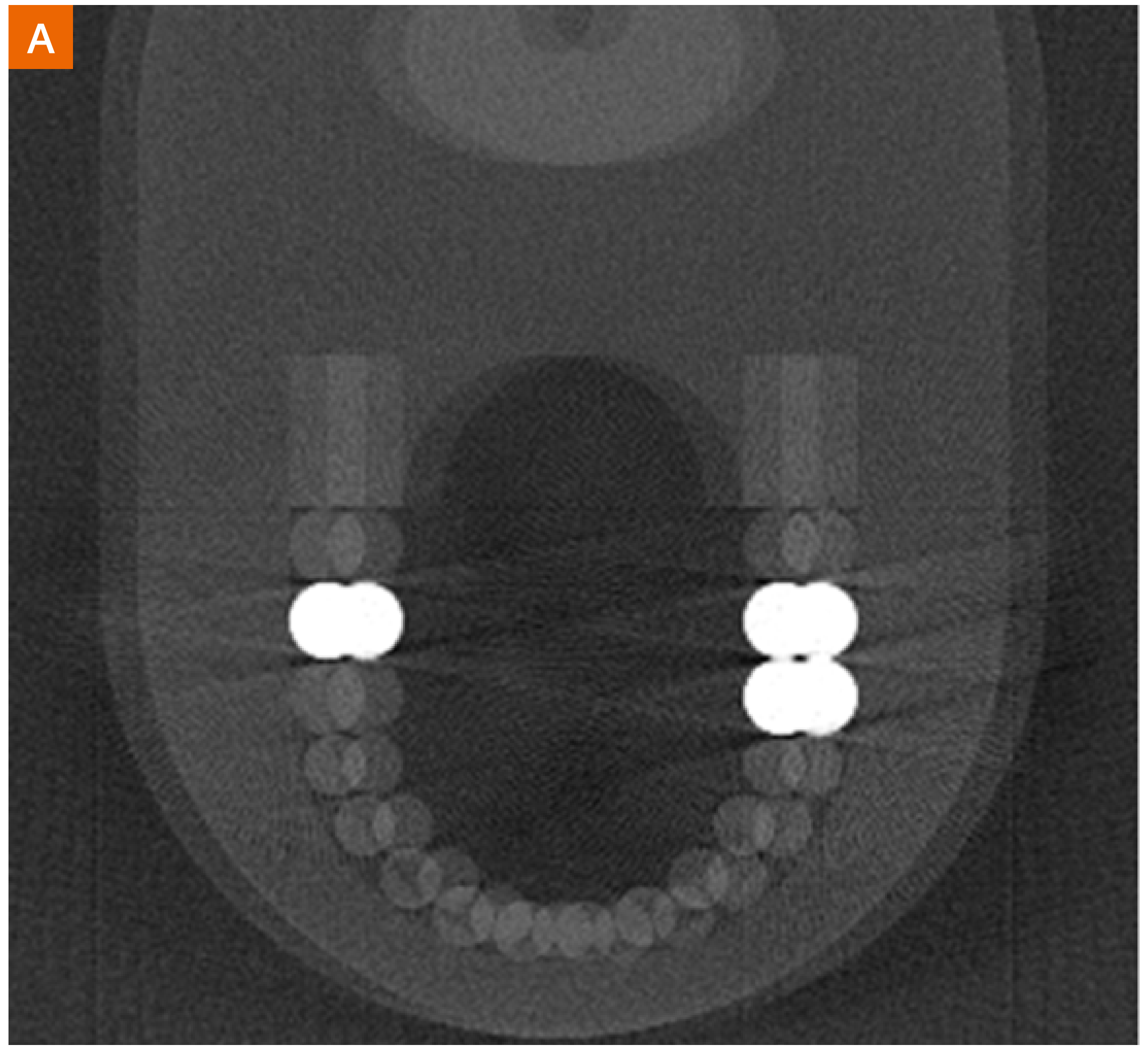
(B) Noise reduction enabled.

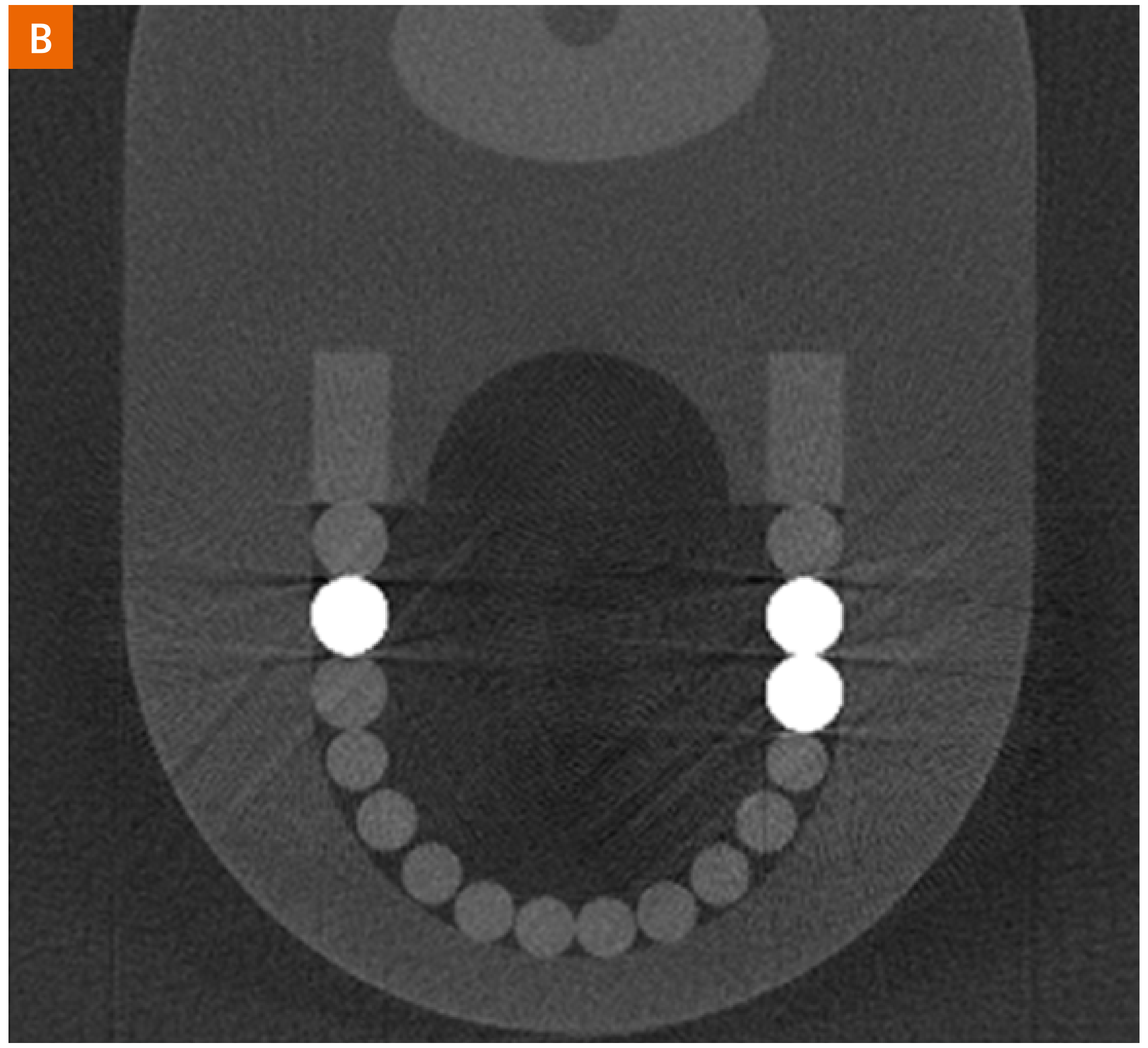
# Patient Motion Compensation




## Allows faster workflows

CERA provides automatic algorithms which simultaneously compensate for rigid patient motion and instabilities of the system mechanics during the scan. These algorithms enable faster workflows due to simplified patient positioning and faster scanner motion. In addition, they can be crucial for system design-to-cost by balancing costs between mechanical stability and compute power.




(A) Alignment compensation disabled.

(B) Alignment compensation enabled.

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NDT Applications
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Dental Imaging
(Super) Short-scan Reconstruction
Half-beam Reconstruction
Noise Reduction
Patient Motion Compensation
Metal Artifact Reduction
Reconstruction Speed
How to use CERA
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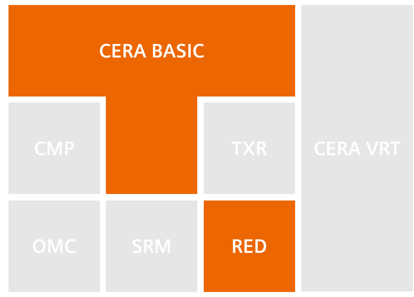
# Metal Artifact Reduction




## Dealing with dental fillings

Dense objects like metallic implants often almost fully occlude anatomical structures and lead to severe artifacts in tomographic reconstructions.

CERA provides innovative metal artifact reduction algorithms that can recover affected structures and therefore significantly reduce these artifacts.

Volume rendering after metal artifact reduced reconstruction.

# Reconstruction Speed

| | FDK | SRM | SRM+MAR | Motion Compensation* |
|---|---|---|---|---|
| **GT 1030[1)]** | 16.5 s | 19.7 s | –** | 154 s |
| **GTX 1650[1)]** | 6.1 s | 7.7 s | 29 s | 101 s |
| **GTX 1070[1)]** | 4.5 s | 5.3 s | 21 s | 92 s |
| **RTX 4000[2)]** | 4.2 s | 4.9 s | 17 s | 90 s |
| **RTX 2080Ti[3)]** | 3.2 s | 3.7 s | 14 s | 90 s |

**Test Setup**
Reconstructing 360 projections of size 1000x1000 pixel (1373 MB) on a volume of 1000x1000x1000 voxels (3814 MB), without I/O CERA 6.1, GPU driver 441.66, Windows 10

[1)] Intel Celeron G5900, 16 GB RAM (total system cost without GPU: 225€ as of August 2020)
[2)] AMD Ryzen 5 3600X, 64 GB RAM
[3)] Intel i9-7900X, 64 GB RAM

** Compensating for a maximum patient movement of 5 mm and a maximum patient tilt of 5°*
*** Due to memory limitations, this configuration is not recommended/implemented*

# How to use CERA

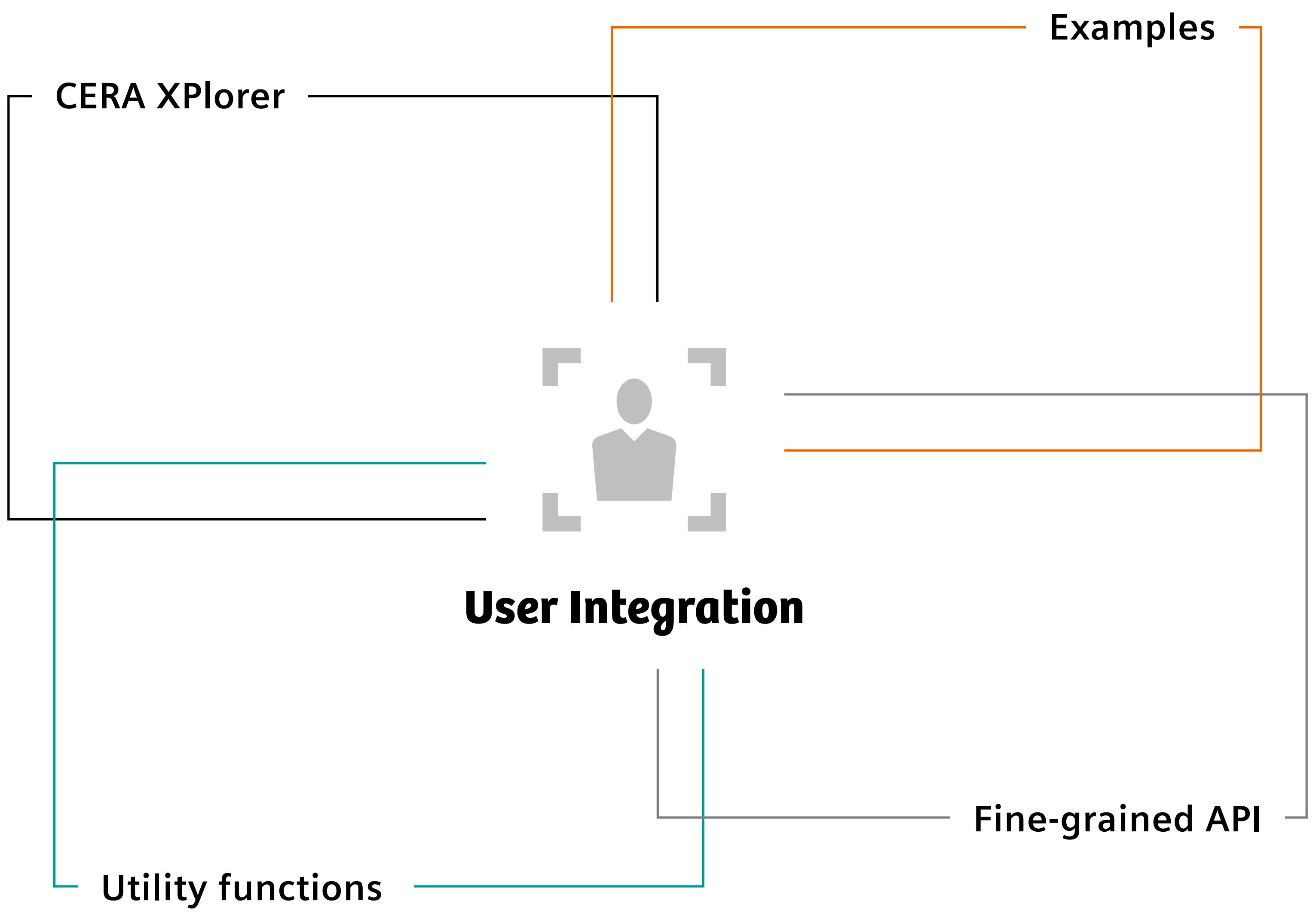
## From out-of-the-box to deep integration: customizable for any needs

In order to be used, CERA requires a Windows 10 system with an Nvidia graphics adapter.

To achieve high-performance, an SSD is recommended for fast I/O. CPU performance, on the other hand, has no significant influence on CERA's processing speed.

CERA can be accessed in a seamless range of depths of integration starting from a comfortable GUI up to an extremely fine-grained API integration. The chosen depth of integration can vary throughout the implementation, utilizing:

- **CERA XPlorer**, an intuitive front-end application, offering an easy entry point and allowing fast prototyping.
- **Ready-to-use examples** for most CERA features that come as pre-compiled programs and as C++ source code.
- An easy-to-do **high-level C-API** integration, based on text based configuration files that separate source code from feature and system configurations.
- The **low-level C-API** allowing fine-grained control of all CERA features for a completely customizable workflow.

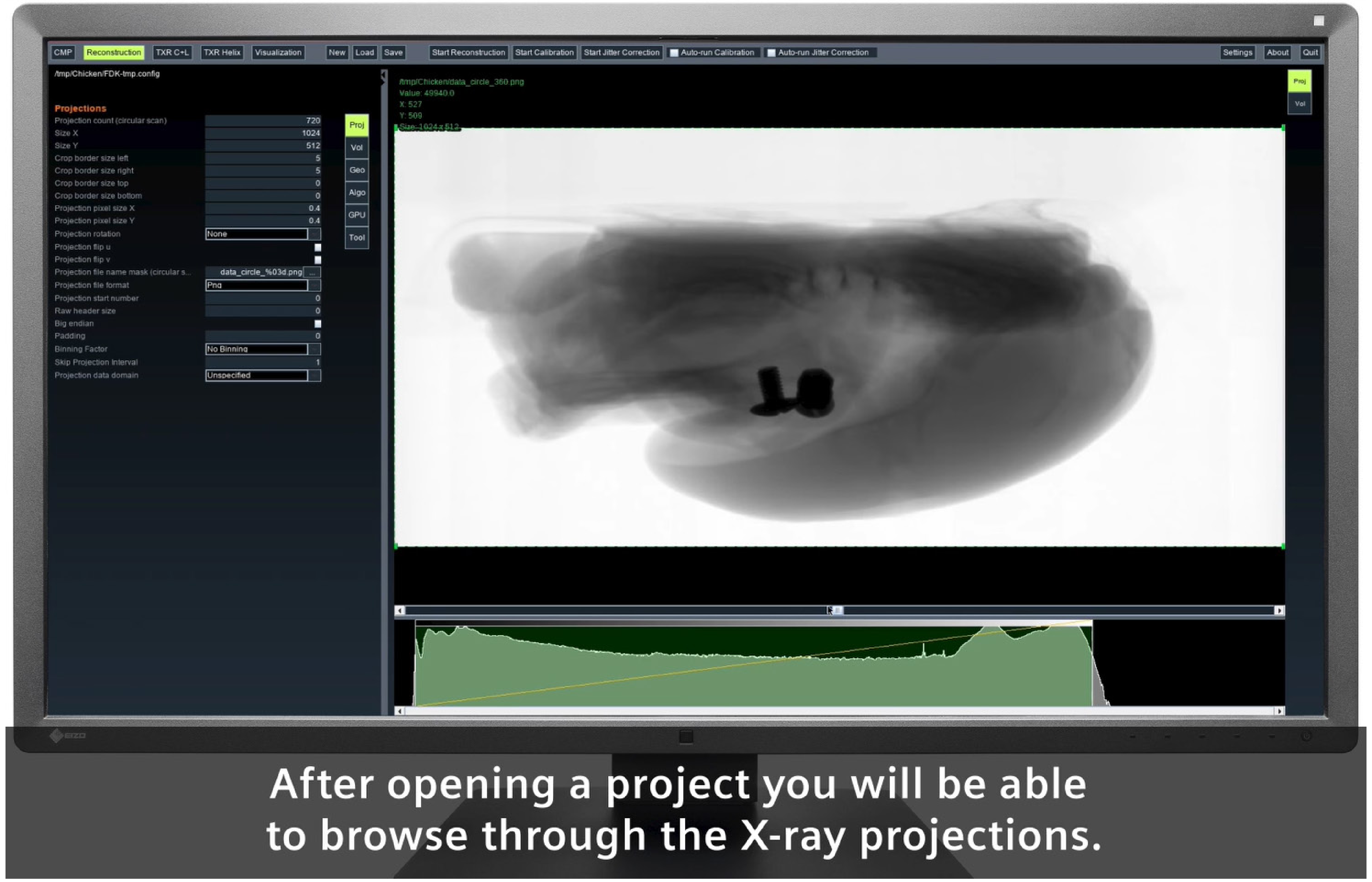


# CERA XPlorer

The CERA XPlorer is an intuitive and efficient front-end for exploring most CERA features. It can be used for rapid prototyping and also as an end-customer application.

CERA XPlorer's functionality can be extended by executing customized command-line tools directly from its GUI. These can be the ready-to-use CERA examples or customer-created tools. This allows automatic, task-specific workflows to be created easily.

Video



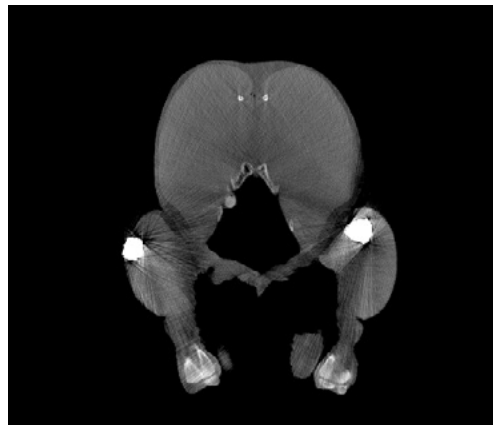
# API based CERA Integration

## Listing 1

```
#include <cera.h>
#include <ceraUtil.h>
#include <string>
int reconstruction(std::string configFileName)
{
  // create handle for reconstruction pipeline
  ceraPipelineFdk* pipeline = nullptr;
  ceraPipelineFdkCreate(&pipeline, ceraDataTypeFloat);

  // create handle for configuration file and read
  // complete configuration from file
  ceraConfigFile* configFile = nullptr;
  ceraPipelineConfigureFromFile(
    pipeline, &configFile, configFileName.c_str());

  // configure reconstruction behavior
  ceraUtilPerformReconstructionParameters params = { 0 };
  params.autoWrite = CERA_TRUE; // write volume to disk

  // run complete reconstruction reading projections from
  // disk and writing volume to disk as configured
  ceraUtilPerformReconstruction(
    pipeline, configFile, &params, nullptr);

  // cleanup
  ceraConfigFileDestroy(pipeline, configFile);
  ceraPipelineDestroy(pipeline);

  return 0;
}
```

**Result from Listing 1.**

Primitive Integration via Configuration File



**Result from Listing 2.**

Mixed Integration via Configuration File and additional API-based Configurations

## Listing 2

```
#include <vector>
#include <fstream>
int reconstruction2(std::string configFileName, std::vector<float>& volume)
{
  // create handle for reconstruction pipeline
  ceraPipelineFdk* pipeline = nullptr;
  ceraPipelineFdkCreate(&pipeline, ceraDataTypeFloat);

  // create handle for configuration file and read complete configuration from file
  ceraConfigFile* configFile = nullptr;
  ceraPipelineConfigureFromFile(pipeline, &configFile, configFileName.c_str());

  // Here are some high-level API functions that configure reconstruction
  // behavior differently than the configuration file does
  // ------------------------------------------------------
  // fix geometric deviations
  ceraComputeAndApplyAutoAlignmentFromConfig(pipeline, configFile, nullptr);
  // enable correction of ring artifacts
  ceraPipelineRingArtifactReductionEnable(pipeline, CERA_TRUE);
  // reduce metal artifacts
  ceraPipelineMetalArtifactReductionEnable(pipeline, CERA_TRUE);

  // configure reconstruction behavior
  ceraUtilPerformReconstructionParameters params = { 0 };
  params.autoWrite = CERA_FALSE; // do not write to disk

  // read the configured volume size and configure the reconstruction to return
  // the volume in RAM by providing a pointer
  size_t sizeX = 0, sizeY = 0, sizeZ = 0;
  ceraPipelineGetVolumeSize(pipeline, &sizeX, &sizeY, &sizeZ);
  volume.resize(sizeX * sizeY * sizeZ, 0);
  // tell the reconstruction to return the volume in RAM
  params.volumePtr = volume.data();

  // run complete reconstruction reading projection from
  // disk and provide the resulting volume in RAM
  ceraUtilPerformReconstruction(pipeline, configFile, &params, nullptr);

  // cleanup
  ceraConfigFileDestroy(pipeline, configFile);
  ceraPipelineDestroy(pipeline);

  return 0;
}
```

# Main Benefits

CERA delivers software building blocks enabling fast development of cutting-edge tomographic X-ray imaging devices. The access to high-end CERA algorithms allows our partners to focus their R&D on the specific requirements of their application.

- Benefit from a long-time stable programming interface that decouples your software from the fast life cycle of underlying computer hardware
- Utilize the performance benefits of GPUs without extra implementation efforts
- Gain access to innovation and technologies from other X-ray imaging markets where solutions for your questions may have already been found
- Benefit from direct expert-only support automatically included in a commercial license

# Customer Contact

We are constantly working on our CERA feature portfolio and taking up new market challenges and their technological requirements from our customers.

Whenever you are interested in using our imaging solutions, please contact us. A motivated, dynamic and reliable team from Siemens Healthineers will take your needs on board.

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These components and configurations are not finished medical devices. Compliance with all laws and regulations that are applicable to finished medical devices is the responsibility of the assembler/manufacturer of the finished medical device.



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